

STATIC STRUCTURAL ANALYSIS OF CATERPILLAR D70 FORKLIFT WITH DIFFERENT MATERIALS APPLIED TO MAST AND ARMS ASSEMBLY

HAYDAR SHAMKHI JABER ALSALAMI

Master of Technology, JNTUH College of Engineering, Department of Mechanical Engineering
(Engineering Design), Kukatpally, Hyderabad, India

ABSTRACT

This article illustrates a research, involved the optimization of forklift mast & arms assembly in order to control the deformation, maximum shear stress, von-mises strain and stress since the stiff mast channels and arms are planned to resist bending for safe handling of the designed load. The analysis is to be fulfilled by 3D model of the whole forklift structure and carried out in terms of strength and stiffness by means of F.E.M. technique using ANSYS 14.5 to compare two types of low cost high strength composite materials which are (Ductile cast iron GGG-70 as a matrix and reinforced by a 5% Ultra high modulus Carbon fiber) and (Ductile cast iron GGG-70 as a matrix and reinforced by a 5% Porous Ceramic fiber) along with the original manufacturing material which is (Structural Steel “SAE 15B35H”) for the same loading condition. The Caterpillar DP70N pneumatic tire lift truck is chose as a mathematical model for this work with the extremely endurance load of 7 Tons exerted on the fork arms.

KEYWORDS: Forklift, Finite Element Method, Static Structural Analysis, 3D Modeling

INTRODUCTION

Fork truck is a kind of load and unload transporting machinery widely applied to various worksite such as dock, workshop, building filed, etc. Fork truck frame system is an important mechanism that realize loading and unloading. Force bearing on components is comparatively complicated, and dead weight is comparatively big, the working pose varies with time. Accurate force bearing analyses is very difficult to carry out strenuously aiming at each component if using the graphic method or traditional analytic method [J.J. Liu and D.Q. Wang, 2008].

The fork is the most popular removable equipment item of the fork lift trucks. It consists, most commonly, of two arms attached to the carrying plate of the fork lift truck. Attaching is either by a welded upper console support or by connecting holes. The welded console-supported forks are widespread in practice. The fork arm has a folded (or bent region), due to material roughing which is applied in order to strengthen the bent cross-section. [Yanko Slavchev, 2009].

The lifting installation of fork-lift trucks is a complicated structure subjected to various static and dynamic loads. The optimal design of this structure is of significant economic and technical efficiency importance. It is represented as a construction of beams with a constant cross-section. Its lower end is attached to a pin support and the tilting hydraulic cylinder is represented as a rigid support. The determination of the deformations is done by methods of classical Mechanics and the mast represented as a beam construction bearing the acting load on the designed point distance according to manufacturing material test program. [Georgy Stoychev, Emanuil Chankov, 2009].

PROPERTIES OF THE FORKLIFT

The type of forklift that will be studied is from the manufacturer Cat® DP70N pneumatic tire lift truck which that offers proven reliability and durability, combined with the strength and stability to get the typical applications include loading and unloading goods vehicles; container stuffing and moving goods into or out of external storage areas, as well as transferring items from one site location to another.

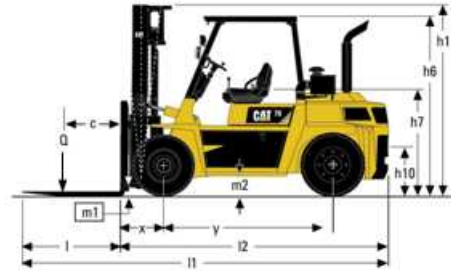


Figure 1: Caterpillar Forklift D70 Dimensions

Table 1: Technical Specifications for Cat Forklift D70

Characteristics	Value
Manufacturer	Cat Lift Trucks
Manufacturer's model	DP70
Power source	Diesel
Operator type	Seated
Load capacity, Q (Kg)	7000
At load center, c (mm)	600
Load distance, x (mm)	585
Wheelbase, y (mm)	2300
Weight	
Truck weight, without load (Kg)	9325
Dimensions	
Height with mast lowered,	3070
Height to overhead guard, h6	2420
Seat height, h7 (mm)	1350
Tow coupling height, h10 (mm)	485
Overall length, I1 (mm)	4855
Length to fork face, I2 (mm)	3635
Fork thickness, s (mm)	60
Fork width, e (mm)	150
Fork length, I (mm)	1220
Clearance under mast, m1 (mm)	140
Clearance at wheelbase, m2	255

MAST & ARM ASSEMBLY

The lifting fork is one of the most important parts of the mast and arm assembly which is the significant part of the forklift. Its job is to grab the load from shelves and move it up and down during the loading process. It is placed in front of the whole truck and connected to the operator cabin. In this work, the lifting fork is subjected to the designed load, and the whole mast and arm assembly is examined different types of materials.



Figure 2: Mast & Arms Assembly

EXPERIMENTED MATERIALS

Sae 15b35h Structural Steel

The materials used were the traditional alloy steels, e.g. SAE 4340, SAE 4140, 42CrMo4, 817M40, SAE 15B35H etc. and the SAE 15B35H is the material used to manufacture the forklift D70 mast and arm assembly which is called Boron Steel alloy also. The essential process features were open die fully forged arms with integral forged heads; requiring machining or boring; a full heat treatment of harden, oil quench, and temper.

The manufacturing processes have been modified to improve the product fatigue life. Steelmaking and casting developments are producing a cleaner and finer grained steel. The combination of increasing strength, from grain refining and the understanding of synthetic and cooling curve analysis have all contributed to the use of boron alloyed steel in the manufacture of fork arms in a wide range of section sizes; up to 300mm x150mm and capacities; up to 55 tonnes @ 1200mm load center.



Figure 3: Boron-Steel Microstructure with a Typical Grain Size of > 9 ASTM According to DIN 50602

In General, Steel is the common name for a large family of iron alloys. Steels can either be cast directly to shape, or into ingots which are reheated and hot worked into a wrought shape by forging, extrusion, rolling, or other processes.

Table 2: Specification Range (wt%) for SAE 15B35H

C	Si	Mn	Cr	Al	Ti	B
0.35	0.35	1.5	0.7	0.04	0.04	0.005

Ggg-70 Ductile Cast Iron

Ductile iron is also known as nodular iron, spheroidal graphite iron or spherulitic graphite iron (SG iron). This

type of iron is much less brittle than other types of iron because of the nodular graphite inclusions. The nodular shaped graphite particles improves the materials impact and fatigue resistance significantly compared to other types of iron. The graphite nodules are created by adding nodulizing elements like magnesium (Mg) or a low amount of cerium (Ce) before applying the casting process. Ductile iron allows castings with larger cross sections than malleable iron.

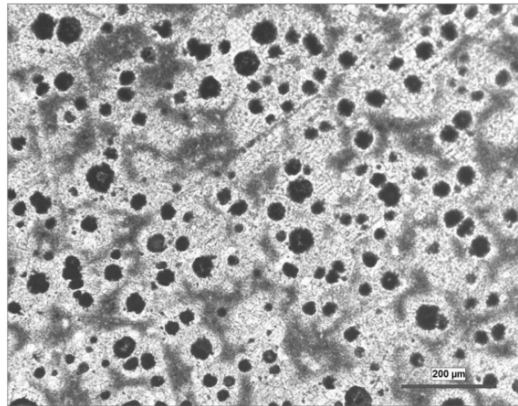


Figure 4: Ductile Cast Iron Microstructure at 100×. Note That Carbon Effect Around Nodules (Wikipedia)

In ductile irons, graphite is in the form of Nodules rather than flakes as in grey iron. Whereas sharp graphite flakes create stress concentration points within the metal matrix, rounded nodules inhibit the creation of cracks, thus providing the enhanced ductility that gives the alloy's name. Nodule formation is achieved by adding nodulizing elements, most commonly magnesium and less often now cerium. Tellurium has also been used.

Table 3: Specification Range (wt%) for GGG-70 Ductile Cast Iron

C	Si	Mn	Cr
3.40	2.40	0.80	0.80

Carbon Fiber Ultra High Modulus

Carbon Fiber, is made of carbon crystals aligned in a long axis. These honeycomb shaped crystals organize themselves in long flattened ribbons. This crystal alignment makes the ribbon strong in the long axis. In turn these ribbons align themselves within fibers. The fiber shape is the original shape of the material (its precursor) used to produce the Carbon Fiber. The most important factors determining the physical properties of carbon fiber are degree of carbonization (carbon content, usually more than 92% by weight) and orientation of the layered carbon planes (the ribbons). Fibers are produced commercially with a wide range of crystalline and amorphous contents variations to modify the various properties.



Figure 5: Microstructure of PAN Carbon Fibers (Reproduced with Permission From International Union of Crystallography ([Http://Journals.Iucr.Org/](http://Journals.Iucr.Org/)), © 1970)

Carbon fibers are classified by the tensile modulus of the fiber. Tensile modulus is a measure of how much pulling force a certain diameter fiber can exert without breaking. Carbon fibers classified as "low modulus" have a tensile modulus below (240 million kPa). Other classifications, in ascending order of tensile modulus, include "standard modulus," "intermediate modulus," "high modulus," and "ultrahigh modulus." Ultrahigh modulus carbon fibers (UHM) have a tensile modulus of (500 million-1.0 billion kPa). As a comparison, steel has a tensile modulus of about (200 million kPa). Thus, the strongest carbon fiber is about five times stronger than-steel.

Table 4: Specification Range (wt%) for Carbon Fiber (UHM)

O	H	N	C
< 1	< 0.3	< 7	> 92

Porous Ceramic

The porous ceramic is made from aluminum oxide and silicon carbide. The strong, uniform porous ceramic has 40-50% open porosity with a tortuous pore structure and is available in pore sizes ranging from 0.25 to 90 microns. Monolithic, single grade, aluminum oxide porous ceramic is available in 6, 15, 30, 50, 60 and 120 micron pore sizes. Porous ceramics with well-defined macroscopic shapes and high mechanical stability can be fabricated using novel processing route, while retaining the intrinsic porosity of the porous powder from which they are manufactured. Sintering is a thermal process that transforms a compact powder into a bulk material, and is used in mass-producing complex-shaped components.

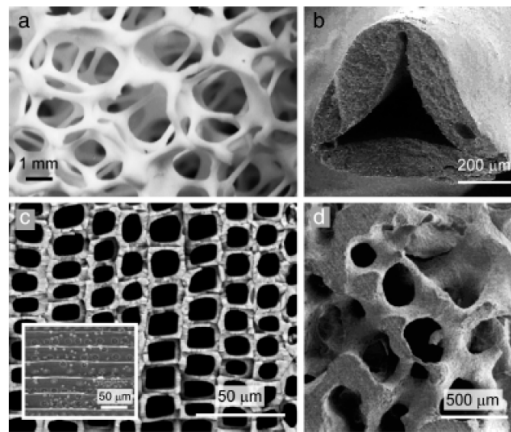


Figure 6: Microstructures of Porous Ceramics Produced Via the Replica Technique. (A) Alumina-Based Open-Cell Structure Obtained Using Polyurethane Sponge Templates (B) Detail of a Strut of a Cellular Ceramic Produced from Polymeric Sponges, Illustrating the Typical Flaws Formed Upon Pyrolysis of the Organic Template (C) Transversal View of a Highly-Oriented SiC Porous Ceramic Obtained After Infiltration of a Wood Template With Si Gas (The Longitudinal View is Shown in the Inset) (D) Macroporous Hydroxyapatite Obtained from a Coral Structure

Table 5: Specification Range (wt%) for Porous Ceramic

Al_2O_3	SiO_2
96.4%	4.6%

Modeling of the Forklift and Process of Analysis

The finite element method (FEM) is a computational technique used to obtain approximate solutions of boundary value problems in engineering. The analysis type used for this purpose is a “*linear static structural analysis*” which is performed to obtain the response of a system in static loading condition. The software used for the analysis is ANSYS workbench 14.5

For a linear static structural analysis, the displacements $\{x\}$ are solved for in the matrix equation below:

$$[K]\{x\} = \{F\}$$

Where stiffness matrix $[K]$ is essentially constant and $\{F\}$ is statically applied.

The following assumptions are applied for the analysis:

- Linear elastic material behavior is assumed.
- Whole 3D model of forklift is subjected to the analysis.
- Only mast & arm assembly material is changed with a composite material.
- The composite material consists of 95% as a matrix and 5% as a reinforcement.
- Total deflection theory is used.
- Equivalent von-Mises Stress theory is used.
- Equivalent Elastic Strain theory is used.
- Equivalent Max Shear Stress theory is used.

- No time-varying forces are considered.
- No vibration or damping are included.

Steps in the Analysis

Pre-Processing (Building the Model) and Geometry

Creation:

The initial geometry was constructed using 3D studio Max 14. The geometry was then converted to suitable format and transferred to ANSYS 14.5 workbench to

Create a finite element model.

Material Property Assignment:

The following properties of the selected materials are defined and assigned in under the “Engineering Data” branch in the ANSYS workbench.

Table 6: Properties of the Selected Materials

Material	Density (Kg/m ³)	Young Modulus (GPa)	Poisson's Ratio	Shear Modulus (GPa)
SAE 15B35H	7850	200	0.3	76.923
GGG-70	7300	185	0.28	72.265
Carbon Fiber	2200	960	0.2	400
Porous Ceramic	3710	375	0.27	147.637

Note that in the first case, the analyzed material is SAE 15B35H Structural Steel. In the second case the analyzed material is a composite material of GGG 70 ductile cast iron reinforced with a 5% of Carbon fiber (UHM). In the third case the analyzed material is a composite material of GGG 70 ductile cast iron reinforced with a 5% of porous Ceramic, the following figure shows a sample of composite material.

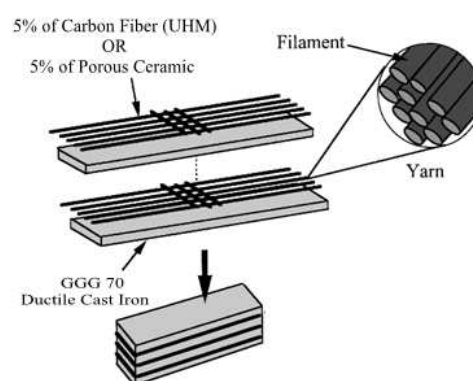


Figure 7: Composite Material used in this Research

Meshing of the Model

Cad geometry is idealization of physical model and mesh is a mathematical representation of cad model. Mesh generation is the process of discretizing the body into finite elements and assembling the discrete elements into an integral structure that approximates the original body.

The model was meshed with high smoothing and default element size for linear static analysis as in the following figure.

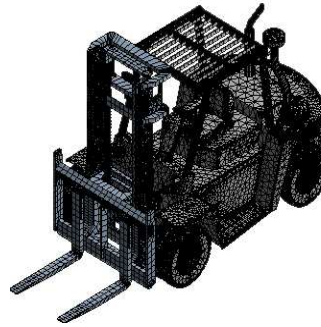


Figure 8: 3D Model Meshing

Boundary Condition Specification

The boundary conditions are applied at the mast & arm assembly according to the forklift design. It is constrained at the welded parts.

Apply Loads

The designed load for the CAT DP70 model is divided into two equal loads each one acting on the one arm of the two arms of the fork.

Solving the Model

Case 1: The material applied to mast and arm assembly is the original manufacturing material which is “SAE 15B35H Structural Steel”, the results were as following:

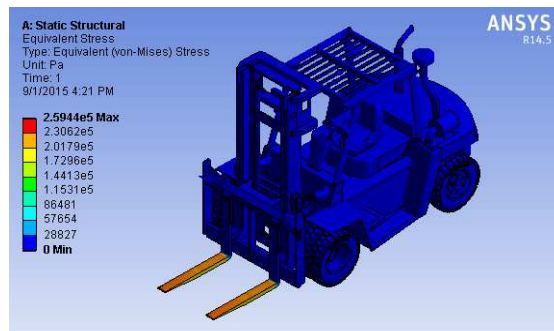


Figure 9: Equivalent (Von-Mises) Stress. Mast & Arm Assembly Material is SAE 15B35H Structural Steel

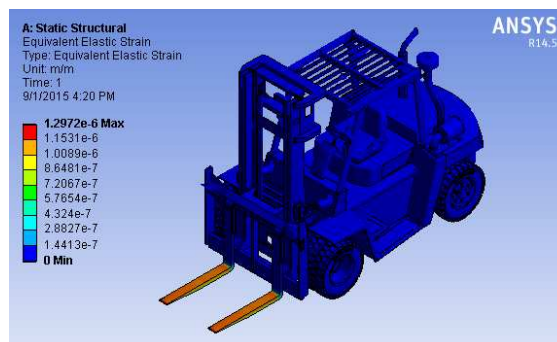


Figure 10: Equivalent Elastic Strain. Mast & Arm Assembly Material is SAE 15B35H Structural Steel

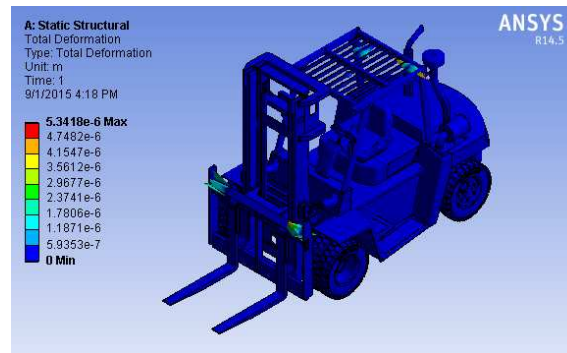


Figure 11: Total Deformation. Mast & Arm Assembly Material is SAE 15B35H Structural Steel

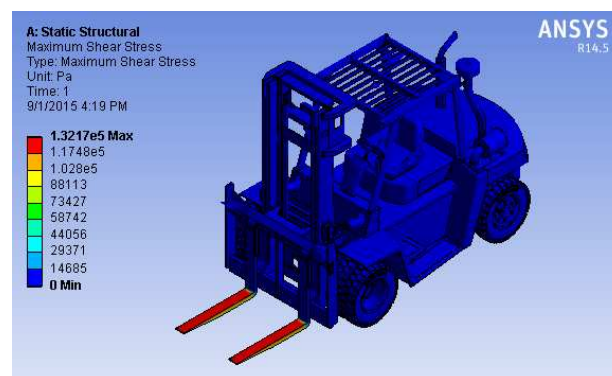


Figure 12: Maximum Shear Stress. Mast & Arm Assembly Material is SAE 15B35H Structural Steel

Case 2: In this stage of analysis the material applied to mast and arm assembly is a composite material consists of “GGG 70 ductile cast iron reinforced with a 5% of Carbon fiber (UHM)”, the results were as following:

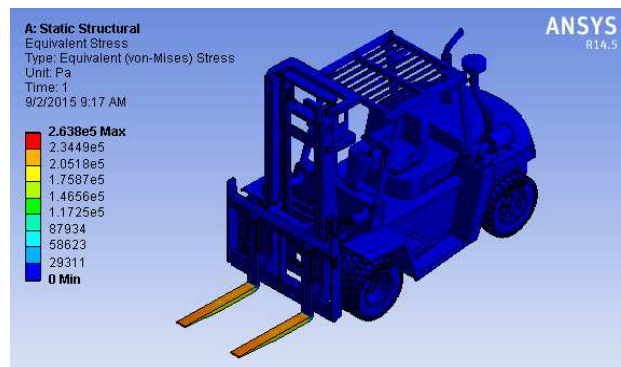


Figure 13: Equivalent (Von-Mises) Stress. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Carbon Fiber (UHM)

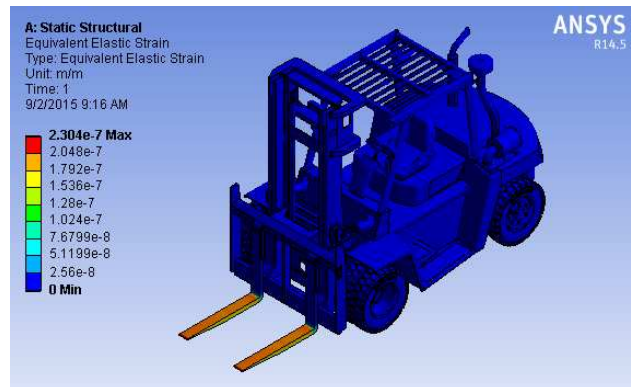


Figure 14: Equivalent Elastic Strain. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Carbon Fiber (UHM)

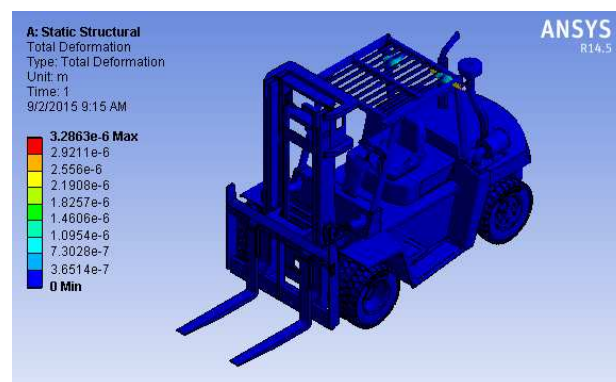


Figure 15: Total Deformation. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Carbon Fiber (UHM)

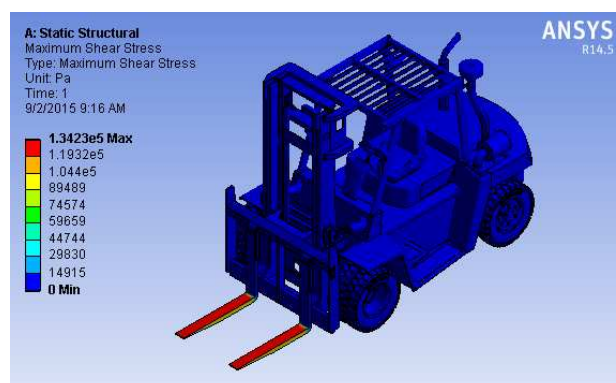


Figure 16: Maximum Shear Stress. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Carbon Fiber (UHM)

Case 3: The material applied to mast and arm assembly is a composite material of “GGG 70 ductile cast iron reinforced with a 5% of porous Ceramic”, the results were as following

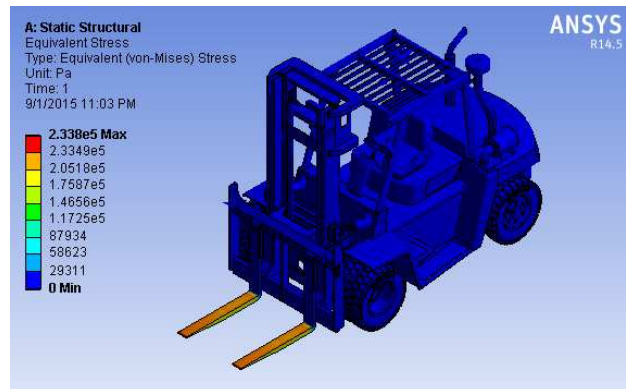


Figure 17: Equivalent (Von-Mises) Stress. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Porous Ceramic

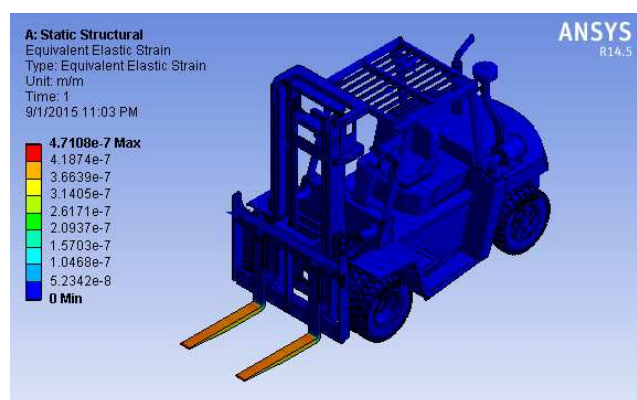


Figure 18: Equivalent Elastic Strain. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Porous Ceramic

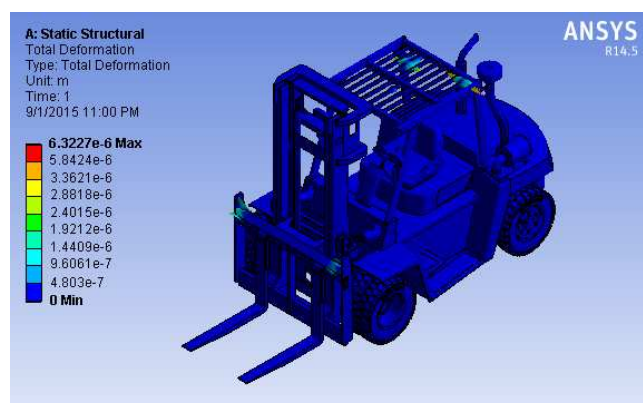


Figure 19: Total Deformation. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Porous Ceramic

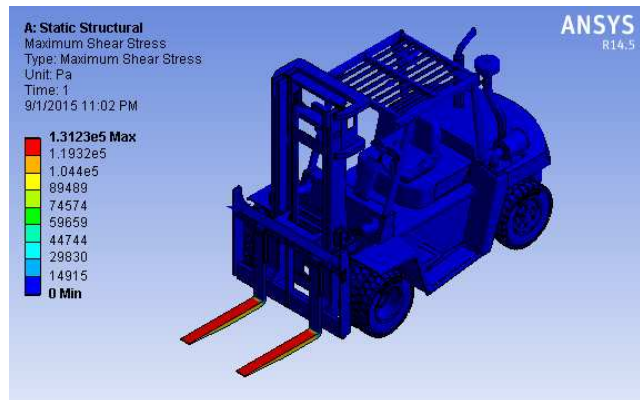


Figure 20: Maximum Shear Stress. Mast & Arm Assembly Material is a Composite Material of GGG 70 Ductile Cast Iron Reinforced with a 5% of Porous Ceramic

For the three cases, maximum deformation occurs on the part named: GC_Body-27 and maximum stress, strain and max. shear stress occurs on the part named: GC_Fork.

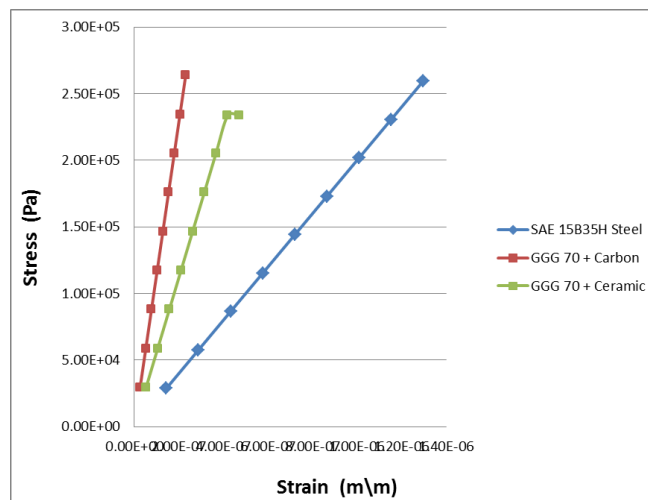


Figure 21: Equivalent (von-Mises) Stress – Elastic Strain Diagram for Three Cases

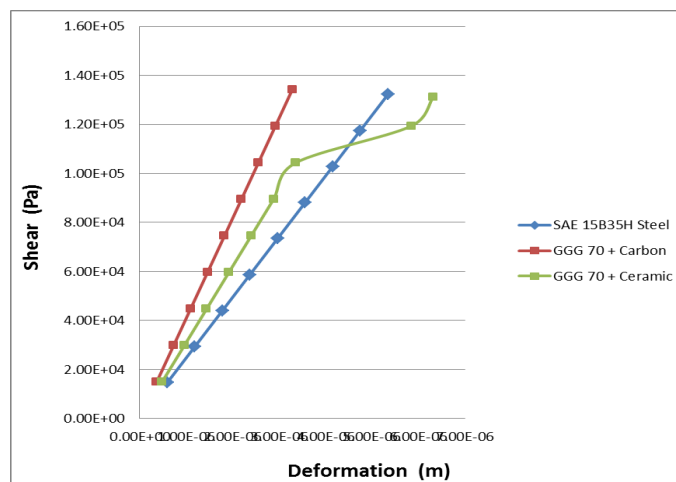


Figure 22: Maximum Shear Stress – Total Deformation Diagram for Three Cases

Table 7: Maximum Results Obtained Using Finite Element Analysis for the Three Cases

Material	Deformation (m)	Stress (Pa)	Strain (m/m)	Shear Stress (Pa)
SAE 15B35H	5.34E-06	2.59E+05	1.30E-06	1.32E+05
GGG-70 + 5% Carbon Fiber	3.29E-06	2.64E+05	2.30E-07	1.34E+05
GGG-70 + 5% porous Ceramic	6.32E-06	2.34E+05	4.71E-07	1.31E+05

CONCLUSIONS

Based on the principles of mechanics, this research proposes integrated model for a loaded forklift truck impacting with a loaded fork arms. Simulation analysis of fork truck frame system was finished by using ANSYS 14.5 which gives calculation results more directly, accurate, and with high efficiency. The comparison made by selecting two composite materials applied to the mast & arm assembly each one alone compared to the original manufacturing material of the assembly. All the required minimum and maximum results are obtained in the process of loading for the linear static analysis which are deformation, stress, strain and shear stress. The following points are significant for indicating:

- From the analysis it is found that the maximum deformation is determined from case 3 and minimum deformation is for case 2.
- Total deformation contour shows that deformation occurs at several parts including mast frame and top of the truck.
- Maximum equivalent stress occurred at the fork arms, the highest value of maximum stress is obtained from case 2 and lowest value of maximum stress is obtained for case 3.
- Lowest value of maximum strain is obtained for case 2 and highest value of maximum strain is obtained for case 1.
- The maximum shear stress has highest value for case 2 and lowest value for case 3.
- The support plate between two side plates of two arms is avoiding bending in inward direction and provides rigidity to structure.

From the above points, case 2 results was the best comparing to other cases. Using composite material consists of GGG 70 ductile cast iron reinforced by 5% of Carbon fibers is a good choice with such a structure could withstand in bending and get more durable in the hard conditions, besides fairly low cost of this type of composites lead to philosophically the safe and economical material.

REFERENCES

1. **J.J. Liu and D.Q. Wang**; Electron Engineering Machine, [2008] No.2, pp.55-59. (In Chinese)
2. **Yanko SLAVCHEV**; 3-D Research on fork arms of forklift trucks, [2009]

3. **Kolarov, I., Slavchev, C.;**Loading and Calculation Cases for Design of Lifting Installations of Fork- lift Trucks, Mashinostroene, No. 6, 1974, pp [21-31
4. **Vaibhav K.Bhagati, P.A. Wankhade;**Development and structural analysis of translation carriage for reach truck, [2012]
5. **Ugale Sachin S.1, Pagare Aakash G.;**Design and Structural Analysis of Mechanical Forklift using ANSYS Software, [2014]

AUTHOR'S DETAILS



Haydar Shamkhi Jaber Alsalami, received his Bachelor Degree in Mechanical Engineering from University Of Babylon, Hilla, IRAQ. Presently he finished his Master Of Technology in Jwaharlal Nehru Technological, College Of Engineering, Design, Hyderabad, INDIA. His research interest includes Nano Technology in Composite Materials.